Climate Change Impacts on U.S. Water Resources

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The Climate Ahead: Impacts of Climate Change on Water Resources
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Pacific Northwest National Laboratory
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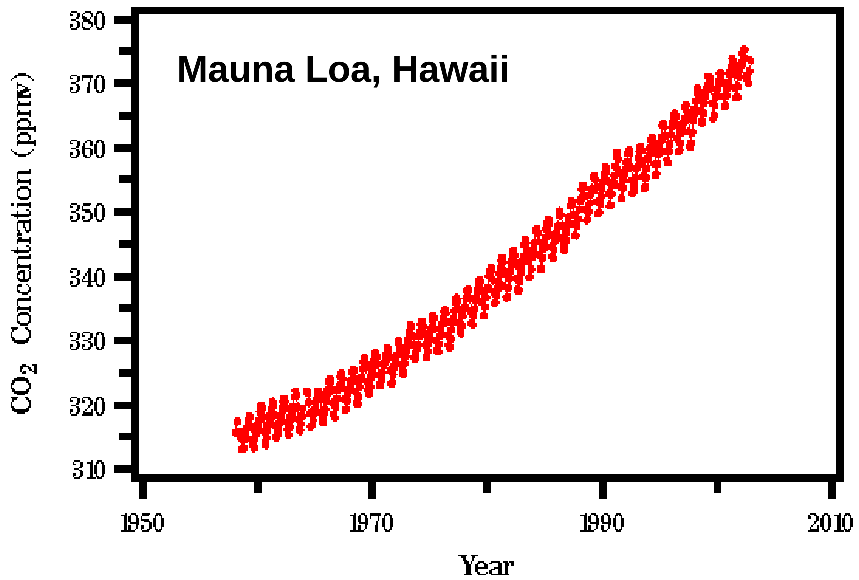
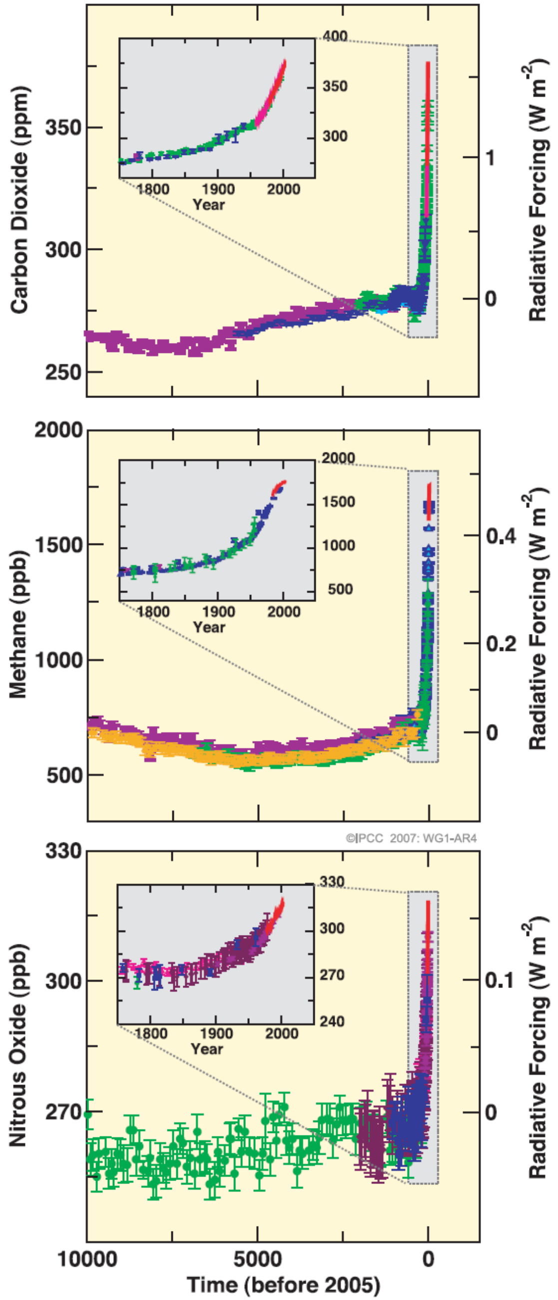
JGCRI
Joint Global Change Research Institute

University of Maryland

The concentration of greenhouse gases has been increasing due to human activities

The continuous rise of CO_2 concentrations in the atmosphere since 1958 follows an oscillating line known as the "Keeling Curve," named after C. Dave Keeling



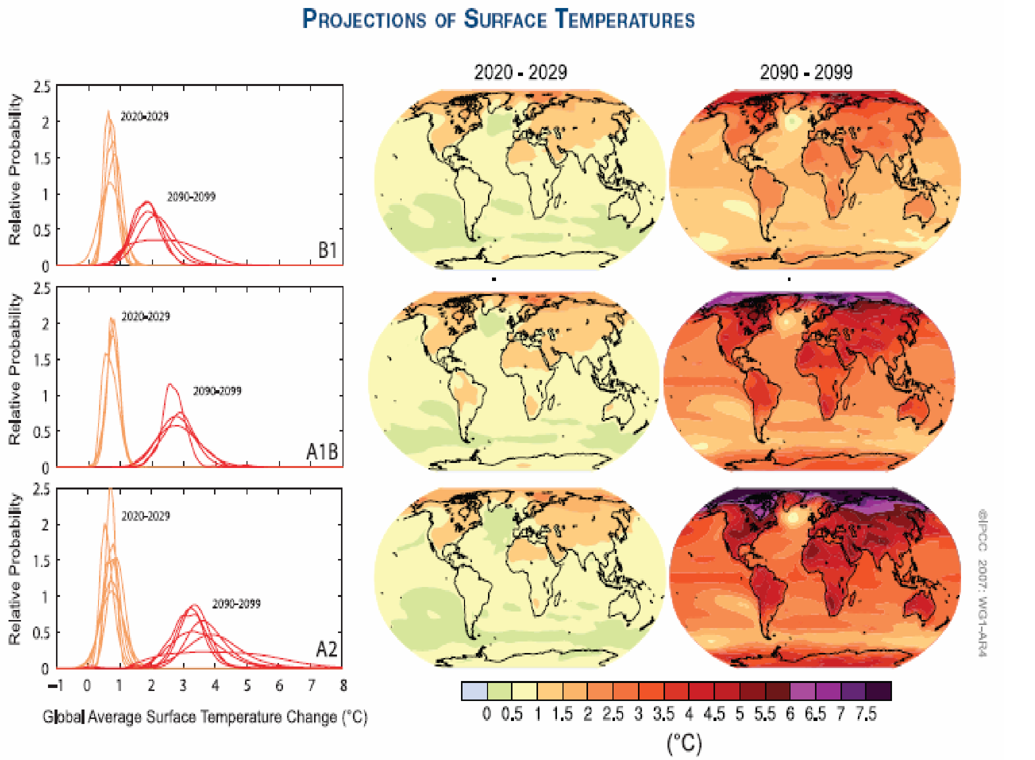


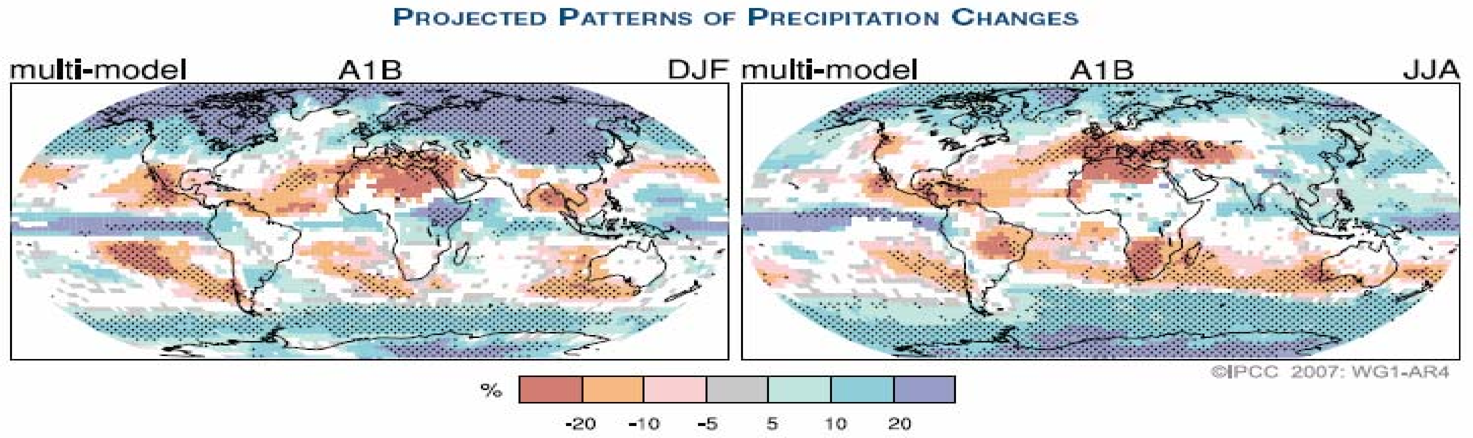
Atmospheric concentrations of CO_2, CH_4 and N_2O have been increasing since 1750 due to human activities and now far exceed past concentrations estimated from ice cores extending over thousands of years

Source: Summary for Policy Makers, IPCC (2007)

The patterns of future changes in temperature and precipitation vary with emission scenarios

Summary for Policymakers, IPCC (2007)



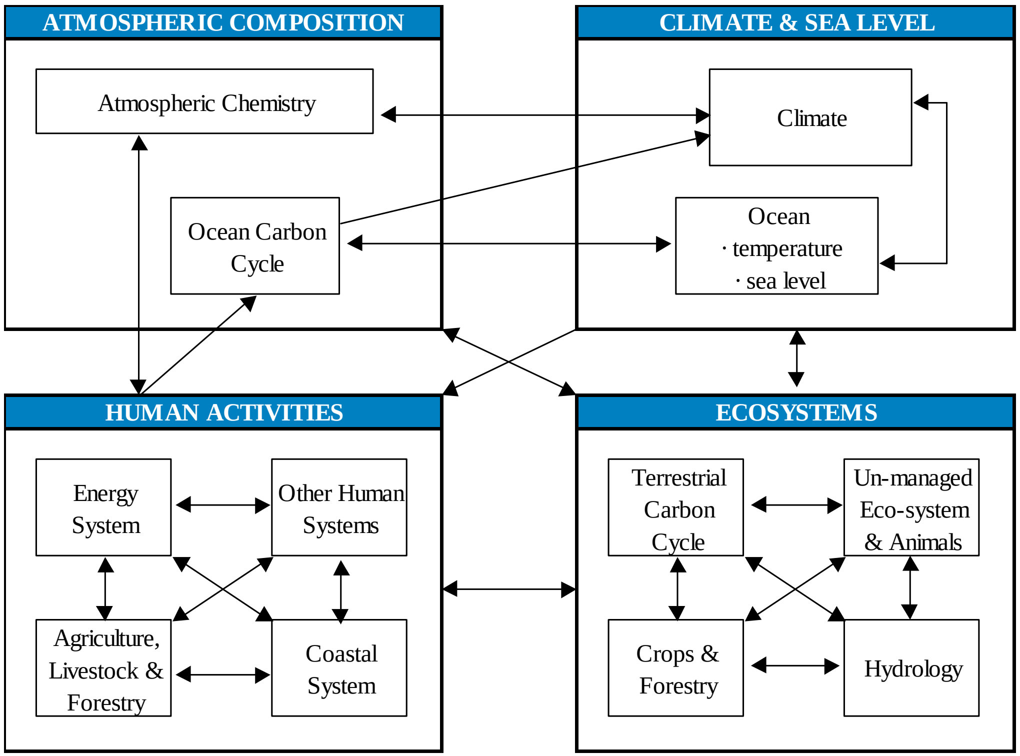


Objectives

- Review results of integrated assessment studies of the impacts of climate change on the water resources of the conterminous U.S.
- Discuss a modeling framework designed to analyze interactions among climate, energy, water and land use

Integrated Assessment of Energy, Economic and Environmental Systems

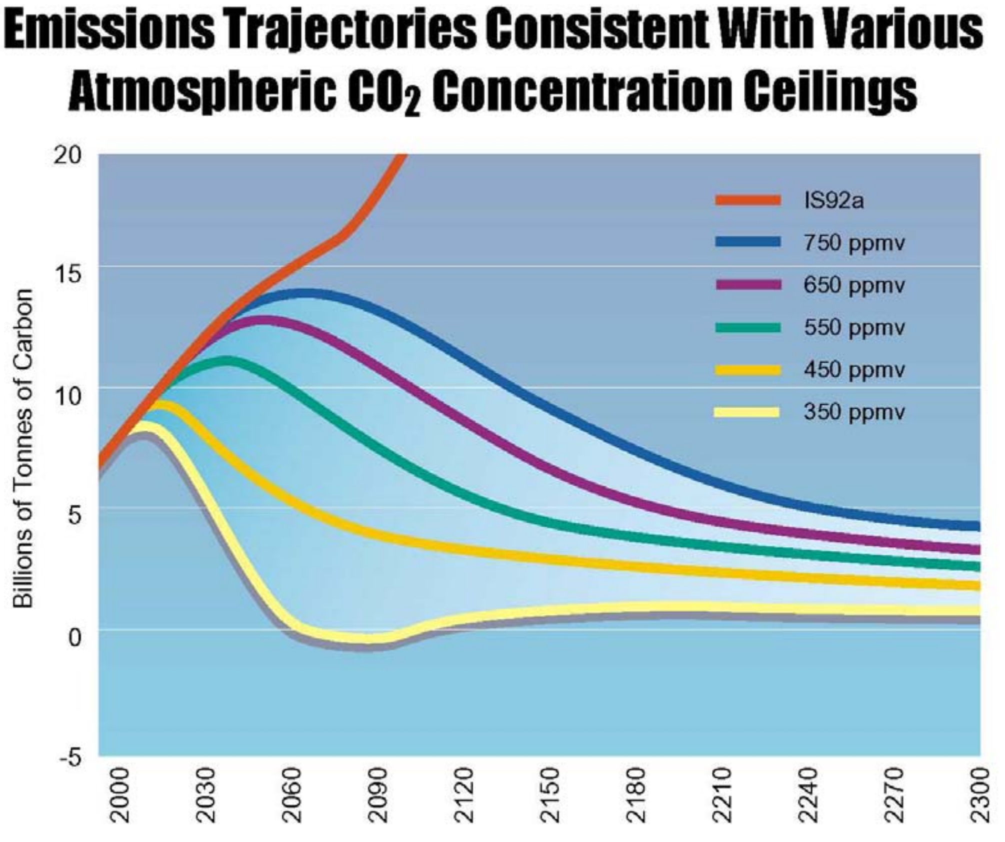
- **MiniCAM—a full integrated assessment model**
  - Energy-economy-emissions module
  - Agriculture and land use (linked to energy and terrestrial carbon cycle)
  - Carbon cycle (MAGICC)
  - Atmospheric chemistry (MAGICC)
  - Climate change (MAGICC)
  - Regional climate change (SENGEN)
- **SGM—full general equilibrium model**
- **EPIC (managed ecosystems, carbon cycle)**
- **HUMUS (hydrology)**
- **BIOME3 (unmanaged ecosystems)**



Integrated Assessment Framework and Modeling Tools Used at the Joint Global Change Research Institute (PNNL / UMD)

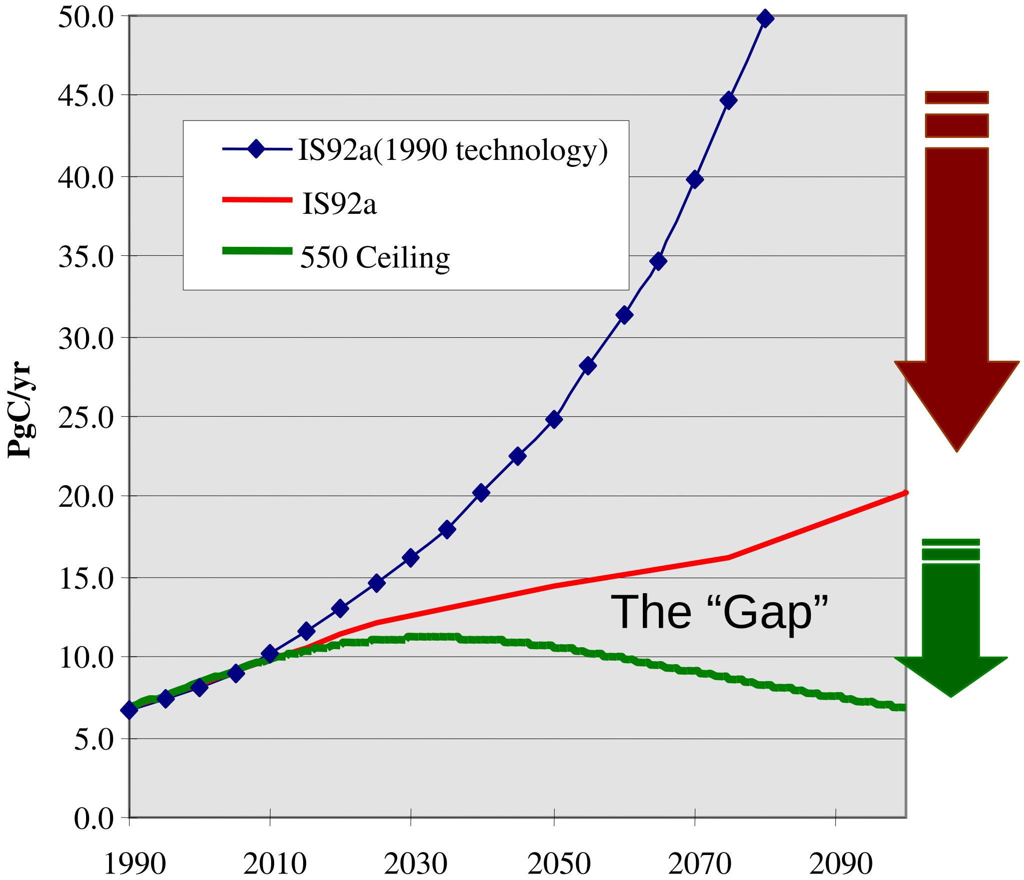
The challenge of stabilizing CO_2 concentrations…

- Stabilization of greenhouse gas concentrations is the goal of the Framework Convention on Climate Change
- Stabilization means that global emissions must peak in the decades ahead and then decline indefinitely thereafter
- Climate change is a long-term, century to millennial problem—with implications for today. It will not be solved with a single treaty, single technology, by a single country, or by a quick fix



Slide courtesy of Jae Edmonds

Filling the Global Carbon Gap… Energy technologies in the pipeline are not enough!

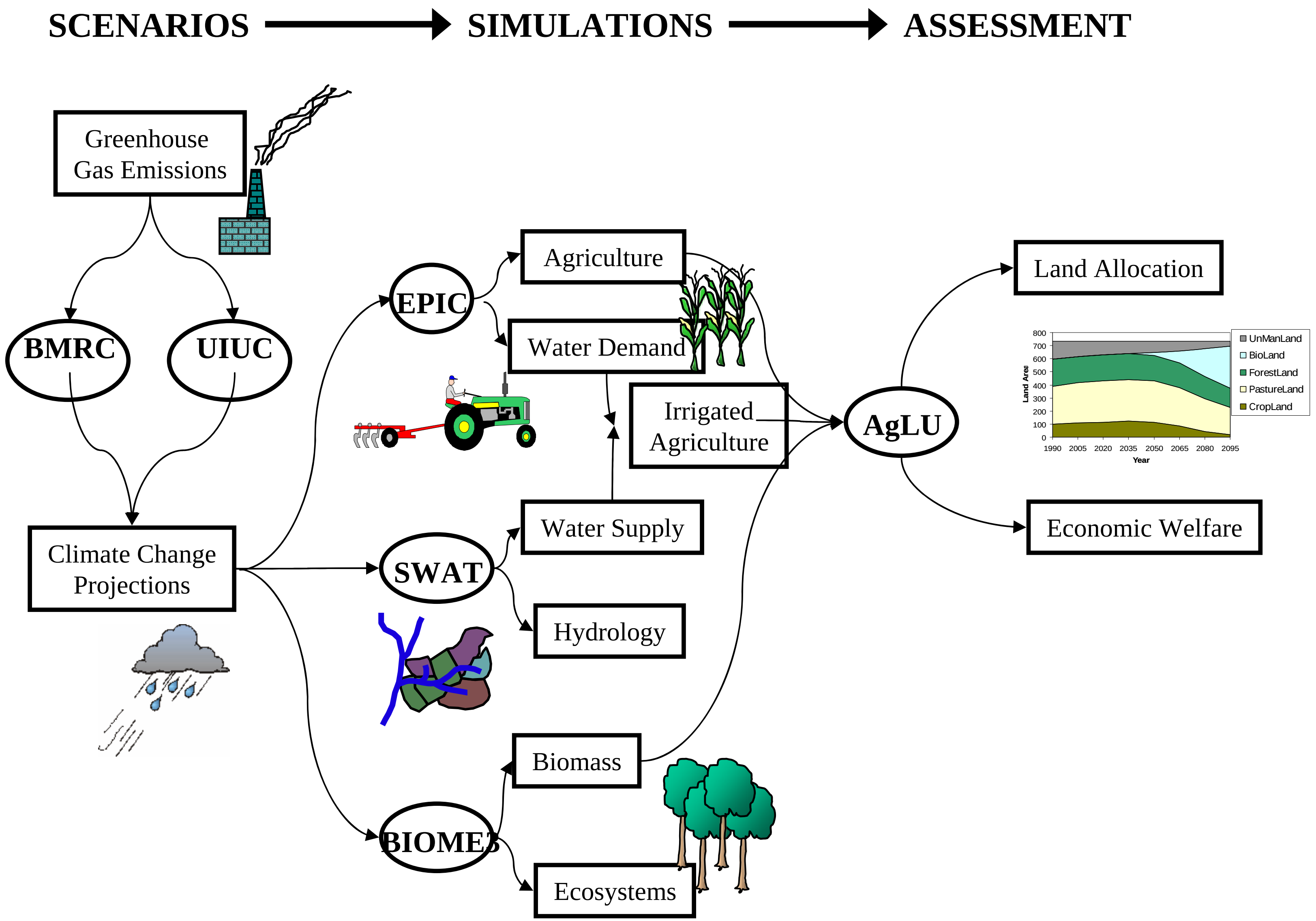


Assumed Advances
- Fossil Fuels
- Energy intensity
- Nuclear
- Renewables

Gap Technologies
- Improved performance of ref tech.
- Carbon capture & disposal
  - Adv. fossil
- H_2 and Adv. Transportation
- Biotechnologies
  - Soils, Bioenergy, adv. Biological energy

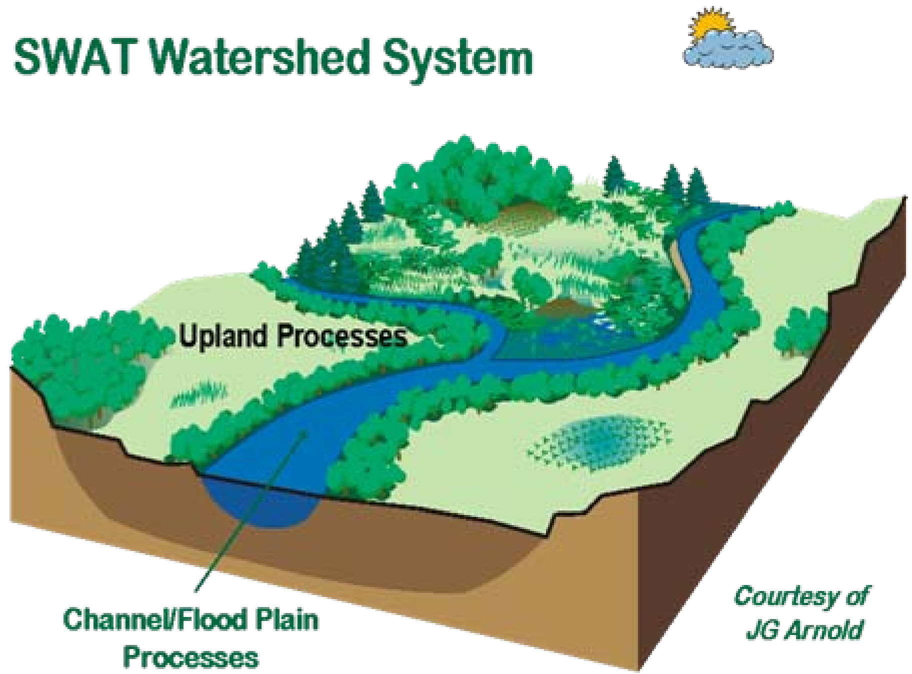
Slide courtesy of Jae Edmonds

Integrated Assessment of Climate Change Impacts on Agriculture, Water Resources, and Unmanaged Ecosystems



SWAT, The Soil and Water Assessment Tool
(Arnold et al., 1998)

- River basin scale model
- Predicts short- and long-term impacts of climate and land management on
  - Water quantity and quality
  - Sediment yields
- Main processes simulated
  - Energy balance
  - Weather
  - Water balance
  - Groundwater
  - Water routing
  - Plant growth
  - Land use, land management

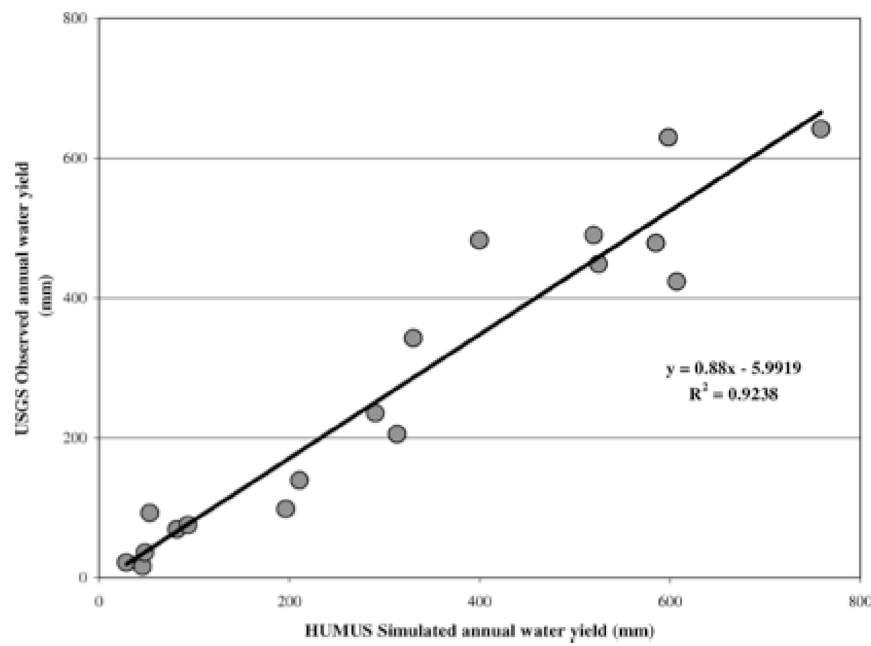


Climate Change Scenarios

- Developed by the US National Assessment Synthesis Team (1998)
- Baseline climatology developed from daily climate records for 1961 - 1990
- Daily climate records (1995 - 2100) for the climate change scenarios developed prepared by the National Center for Atmospheric Research (NCAR) from transient runs of the HadCM2 General Circulation Model
- Future periods selected for analysis
  - 2025 - 2034: 2030
  - 2090 - 2099: 2095

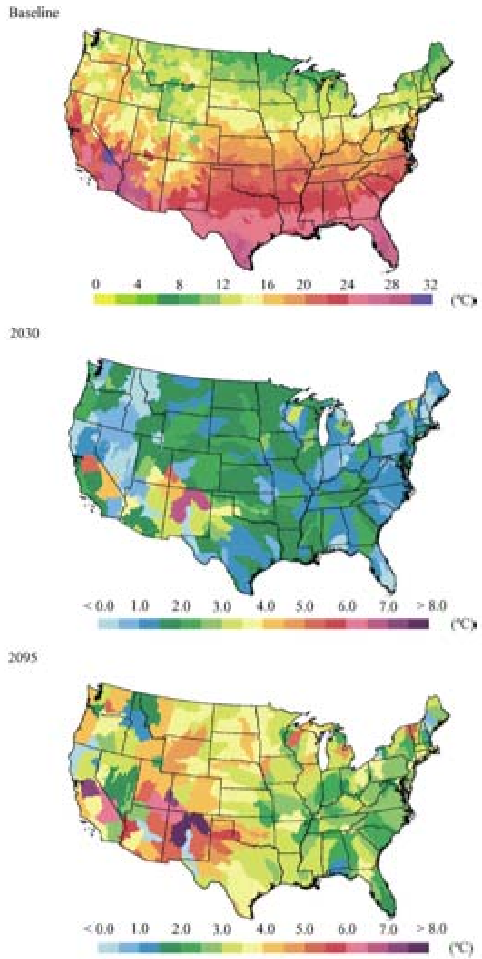
Validation of SWAT model

- Simulated water yield under baseline climate in the 2,202 8-digit basins in the conterminous U.S.
- Compared baseline water yield against streamflow estimates by Wolock and McCabe (1999)
  - Slope: 0.88
  - R^2: 0.92
- Lower agreement was obtained on selected basins (e.g. Lower Mississippi, Missouri, Arkansas-Red-White)

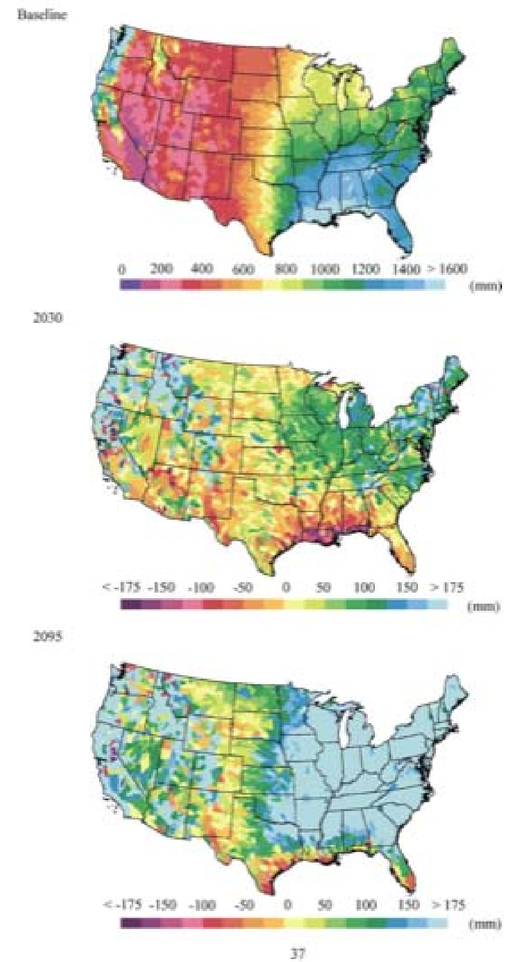


Rosenberg et al. (2003)

Temperature



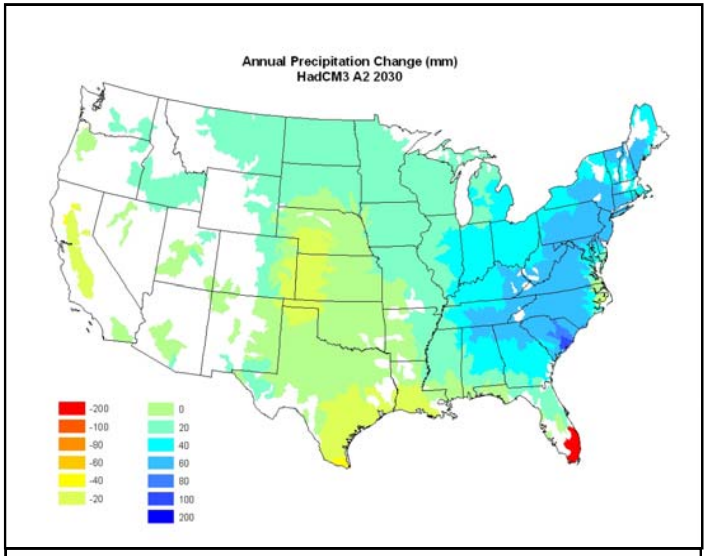
Precipitation



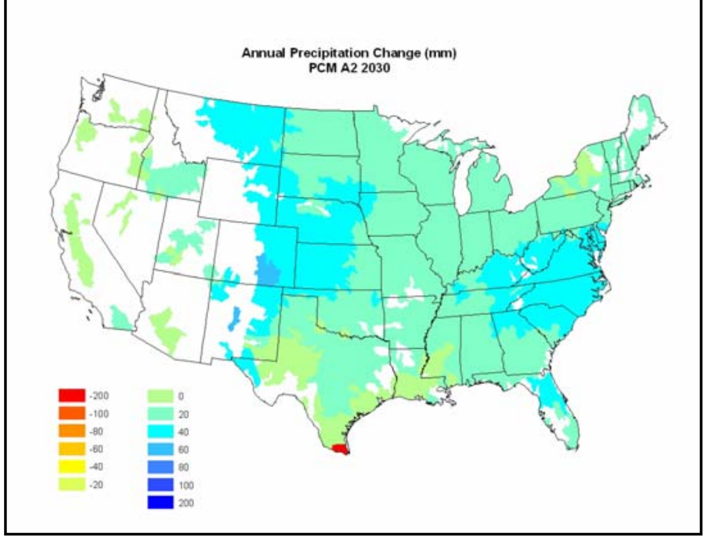
Rosenberg et al. (2003)

Do all models predict the same future?

- Annual precipitation change (mm) predicted with the HadCM3 GCM (Hadley Center) for the period 2030 under the A2 scenario

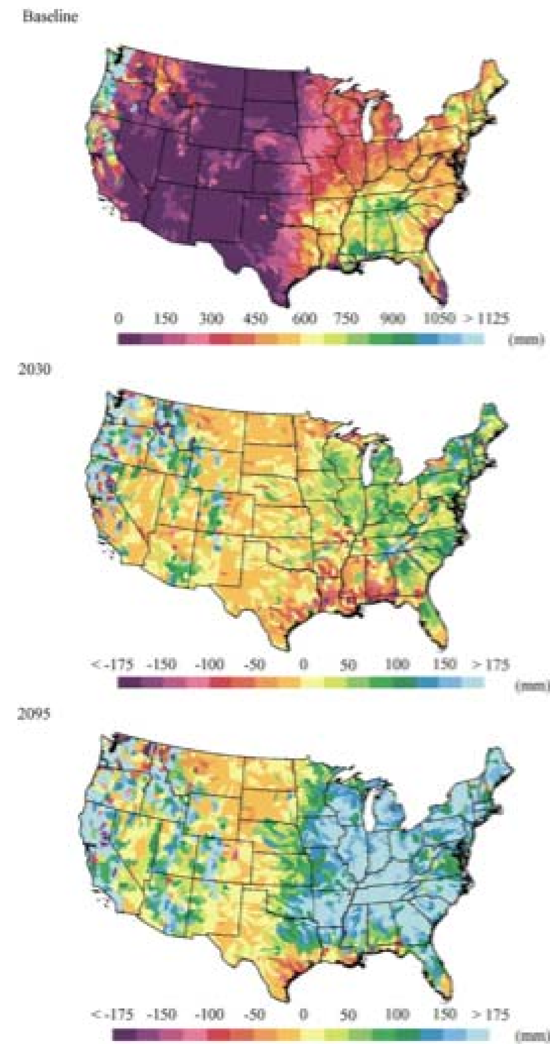


- Annual precipitation change (mm) predicted with the Parallel Climate Model (PCM) GCM (NCAR) for the period 2030 under the A2 scenario



Water yield: baseline and deviations in 2030 and 2095

- In 2030, water yields
  - Increase in the Eastern Seaboard and Midwest
  - Decrease from Alabama to Coastal Texas
- In 2095, water yields
  - Increase in northern portions of the Mountain West and West Coast
  - Increase in eastern portions of the Great Plains from Texas to Nebraska

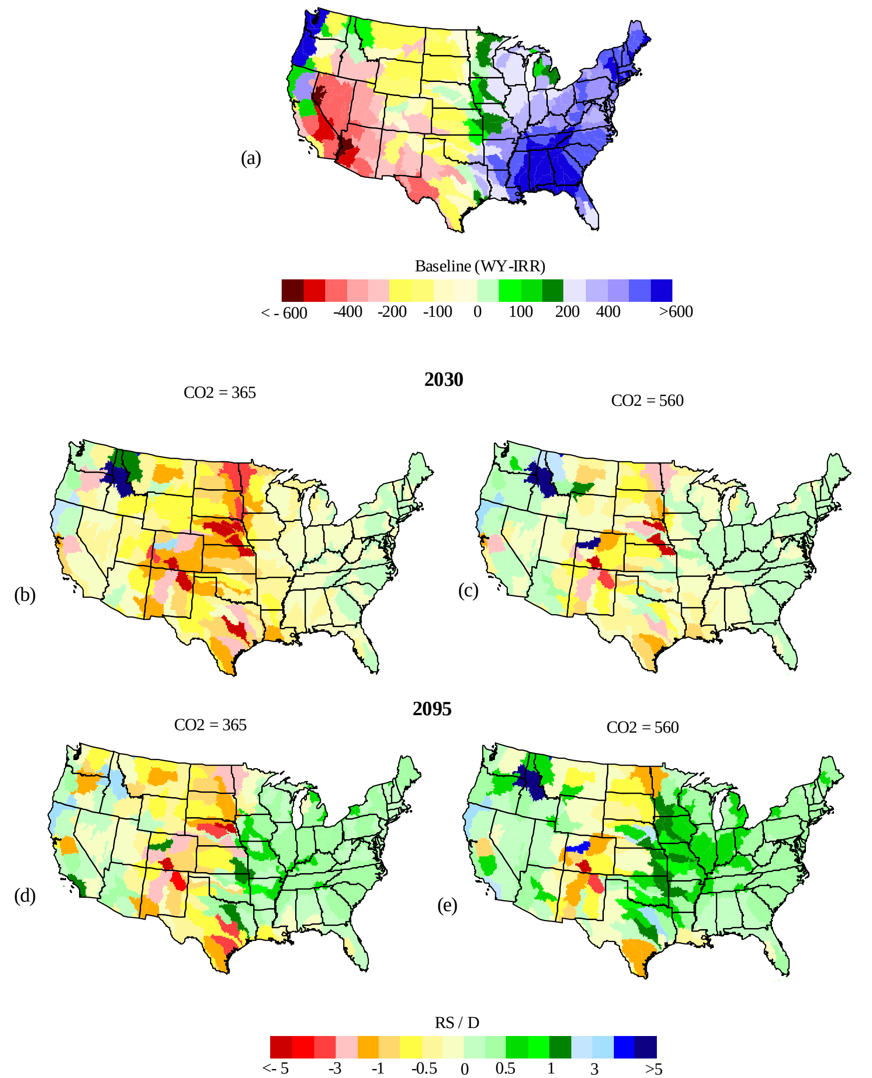


Rosenberg et al. (2003)

Climate change and water tradeoffs

- The EPIC model was used to simulate evapotranspiration (ET) in irrigated agriculture (not shown) for the same baseline and climate change scenarios
- Proxy measure of water supply and demand
  - WY – IRR
    - WY from SWAT
    - IRR from EPIC
- Supply / demand relationship

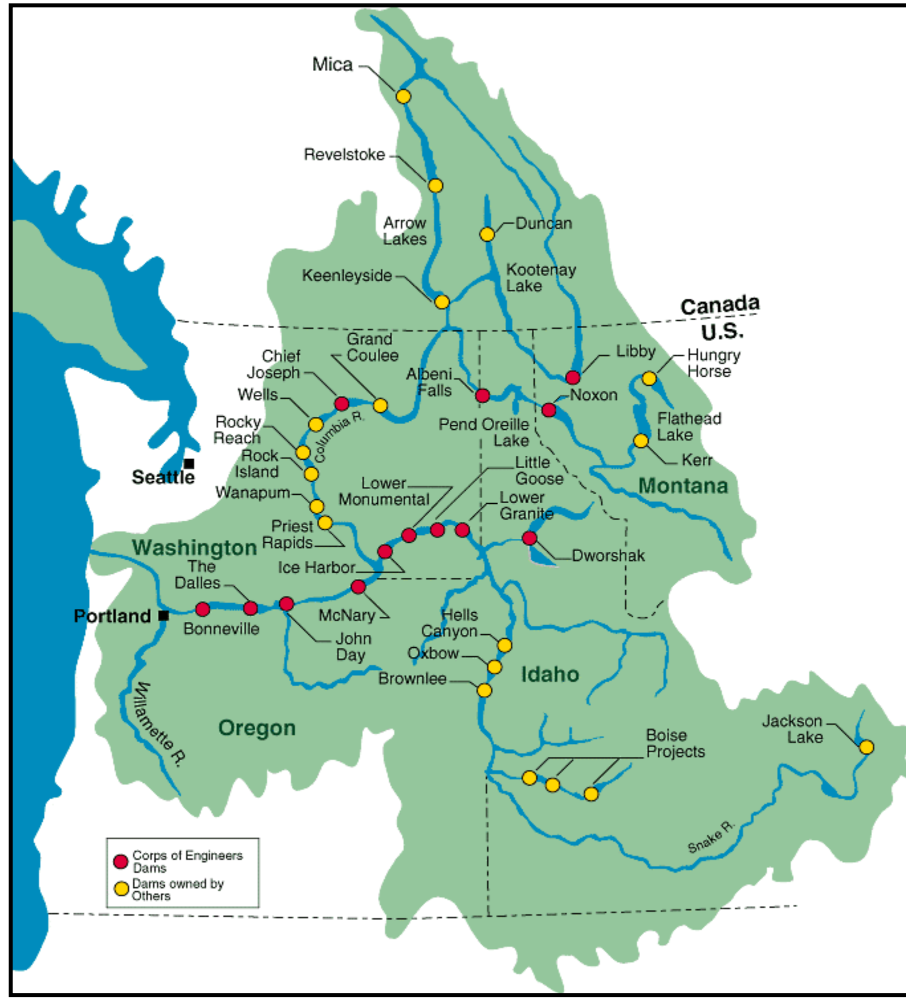
$$R_{s/d} = \frac{\Delta(WY - IRR)_{scenario}}{\left|(WY - IRR)_{baseline}\right|}$$



Izaurralde et al. (2003)

Understanding water supply and demand at the watershed scale: Initial results of an internally funded project (LDRD)

- Water, an essential resource for the 21st century
  - Food and fiber production
  - Household and industrial uses
  - Energy production
  - Transportation
  - Tourism and recreation
  - Functioning of natural ecosystems
- Objective: develop a capability to represent water into an Integrated Assessment framework at a watershed scale
- First test case:
  - A portion of the Columbia River Basin - 150,404 km^2

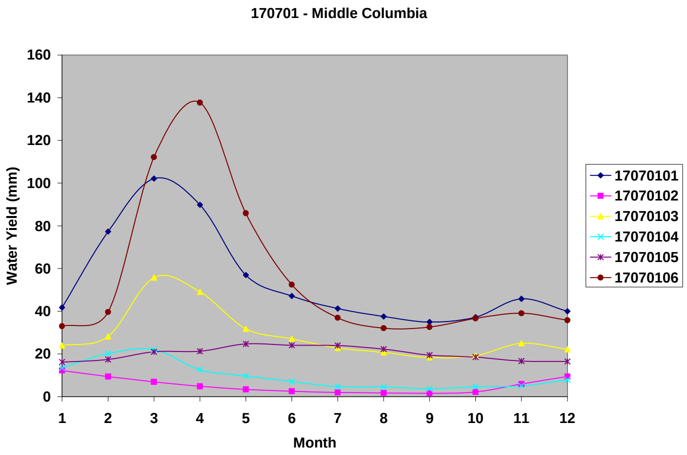


Columbia Basin: 673,397 km^2

Bringing Water into an IA Framework means understanding…

- Climate Change and Variability
  - Changes in snowpack
  - Changes in streamflow
  - ENSO and PDO
- Land Use
  - Agriculture production
  - Biomass energy crops
- Water Demand and Uses
  - Water distribution
  - Socioeconomic issues
- Energy
  - Demand
  - Supply
  - Other energy sources
    - Nuclear
    - Wind
    - Biomass
- Environmental Issues (e.g. fish preservation)

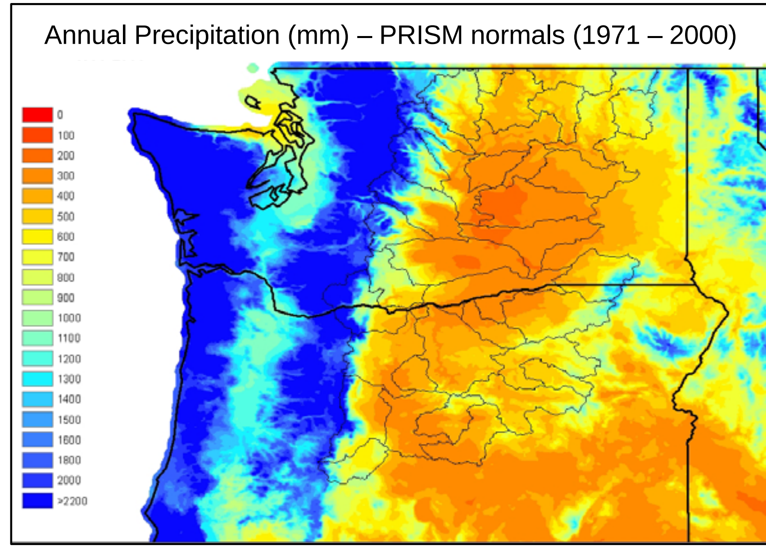
Changes in streamflow

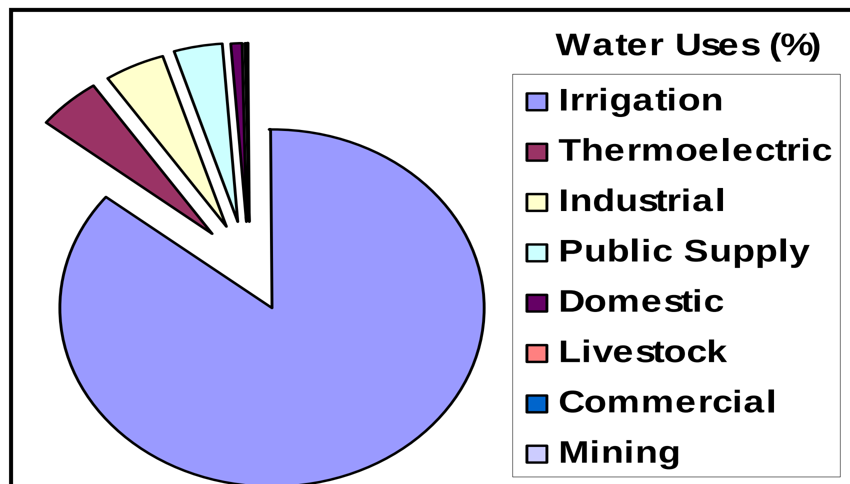


Salmon preservation

Annual Water Fluxes in the Study Region

Sources and Sinks	Water flux (10^{10} m^3 y^{-1})
Columbia R. at Int'l Border streamflow	8.96
Spokane R. streamflow	0.58
Snake R. streamflow	4.70
Precipitation	6.61
Evapotranspiration	-2.95
Consumptive use	-0.49
Columbia R. at The Dalles (<u>Predicted</u>)	17.41
Columbia R. at The Dalles (<u>Observed</u>)	17.01

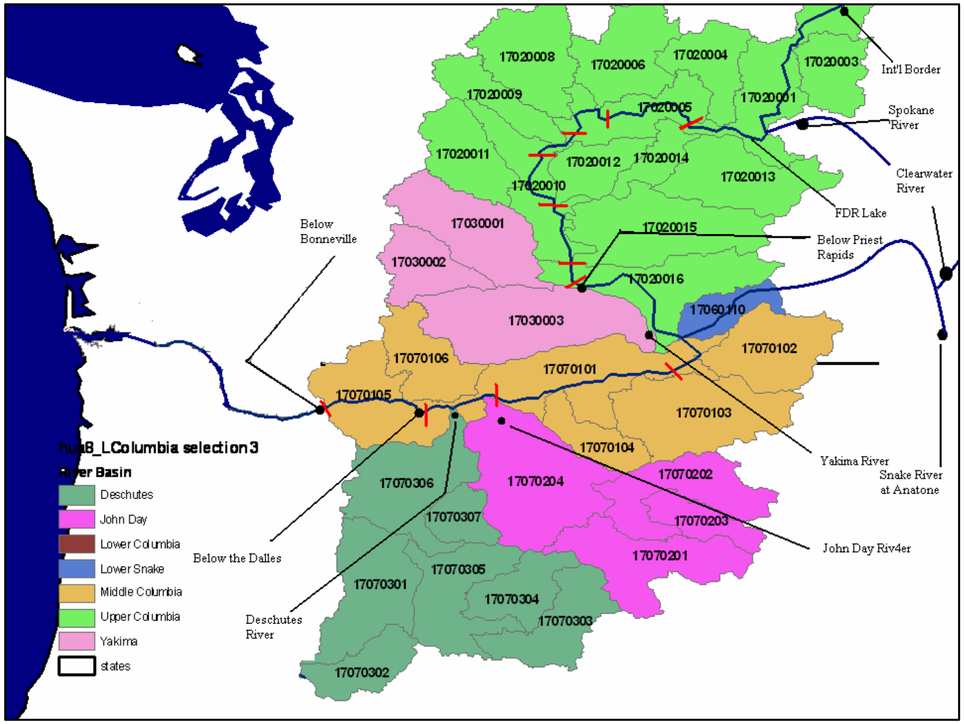




http://www.ecy.wa.gov/programs/wr/cri/Images/PDF/nascrh_covert.pdf

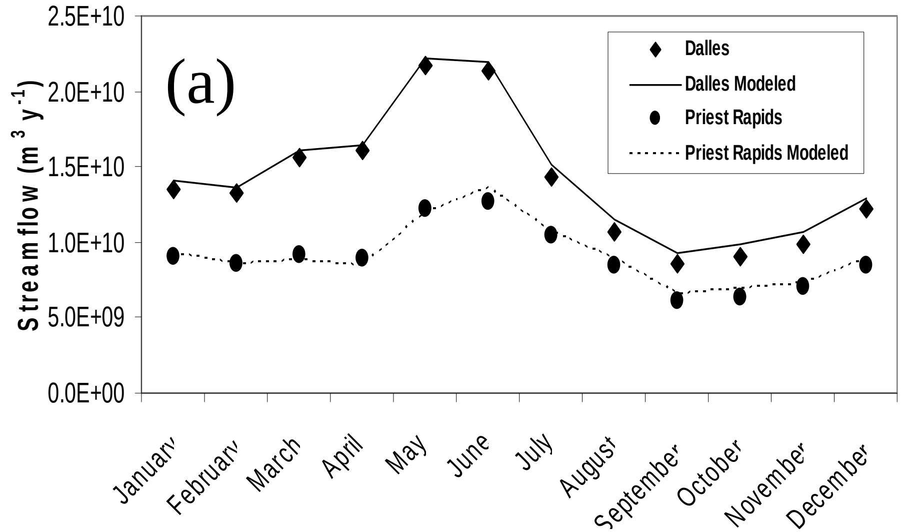
A basin-scale, monthly-time step model prototype of water

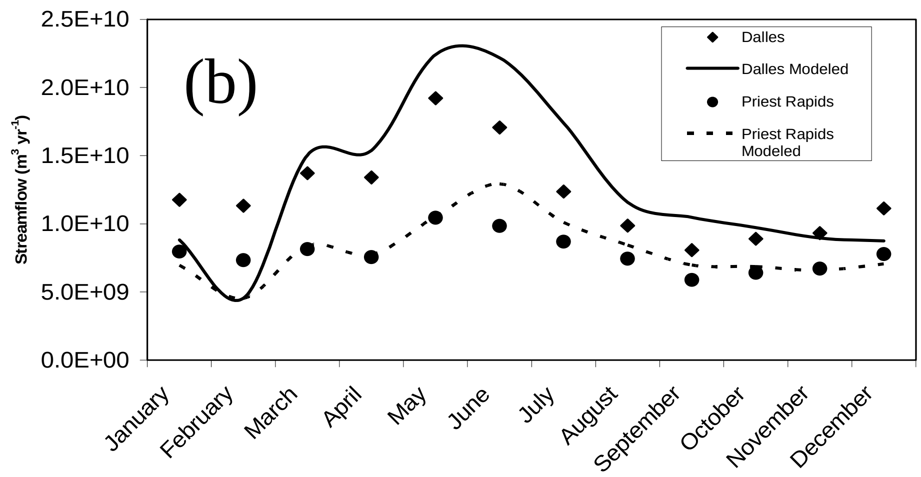
- A monthly time step model to represent
  - Precipitation
  - Modeled evapotranspiration from natural vegetation and crops
  - Streamflow at different locations within the watershed
  - Dams and inflows from tributaries
  - Water use from USGS 1995
    - Irrigation: cereals, fruits, vegetables
    - Electricity
    - Domestic
    - Commercial
    - Industrial



Some results

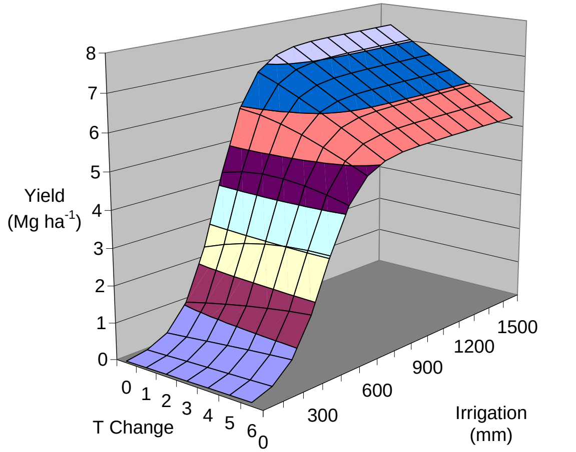
- Predictions of streamflow were within 4% of observations
  - (a) All years
  - (b) El Niño years
- Modeled electricity was 23% greater than the 83 TWh reported in the USGS database

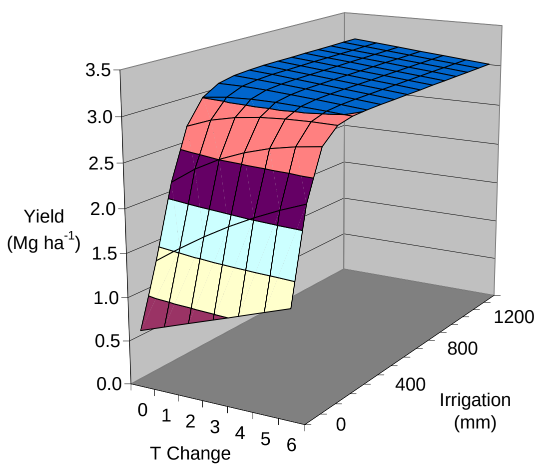


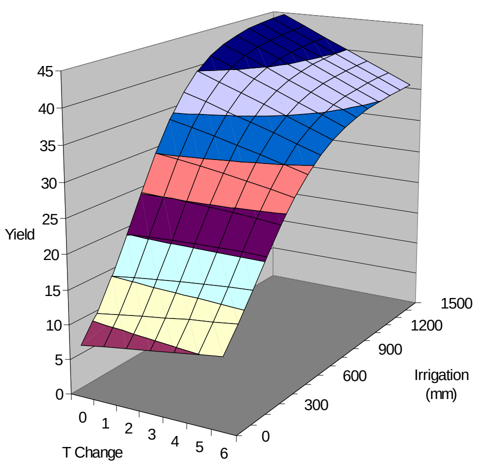


Will irrigation requirements change in a warmer world?

- Climate change scenarios from the Climate Impacts Group at the University of Washington
- Average, maximum and minimum changes projected for 2020, 2040 and 2090 (10 GCM's for A2 and B2 scenario runs for AR4)
- EPIC results used to create irrigation climate response curves.







Summary

- Climate change will have significant impacts on U.S. water resources
- Integrated frameworks are useful to analyze interactions among climate, energy, water and land use